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GEODETIC MONITORING DEFORMATIONS IN MINING SUBSIDENCE FOR GIS APPLICATIONS TO RECLAMATION OF THE MINING LANDSCAPE IN SLOVAKIA

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Abstract. The presented theory of the deformation vector specific solution at monitoring deformations on the Earth's surface as a result of deep mining was developed for the mining subsidence at the abandoned magnesite mine Košice-Bankov near the city of Košice in East Slovakia. The outputs from the deformation survey were implemented into Geographical Information System to needs of a gradual reclamation of mining landscape in Košice-Bankov. After completion of mining operations and liquidation of the mine company it was necessary to determine the exact edges of the mining subsidence Košice-Bankov. Outputs from the presented specific solutions of the deformation vectors confirmed the multi-year stability of the mining subsidence. Some numerical and graphical results from the deformation vectors survey in the abandoned magnesite mine Košice-Bankov are presented. The obtained results in GIS form were used for needs of the Municipality of the city of Košice to implementation of the reclamation works in the mining territory Košice-Bankov.

Keywords: Geodesy, mining, subsidence, deformation, GIS, reclamation.

1. Introduction

On the present in accretive exigencies to people and its property protection, there is security one from priority needs and tasks of all countries or their groupings around the world. In the environment protection, which an unspoiled ecosystem is a condition of human living, it is needed to protect people and its property against the negative industrial influences. Mining activity influence on the environment belongs to the most negative industrial influences. As a result of underground mining of the mineral deposits in the surface creates the land subsidence (mining subsidence), i.e. caving zone (area) dangerous for the movement of people in this zone [8, 9, 10, 18, 20, 27]. The underground coal mining (also ore and non-ore mining) creates voids which are subject to collapse. The collapse of these voids may occur at any time ranging from immediate (i.e., while the mineral is being extracted) to 100 or more years after mining. If the collapse causes sinking of the ground surface, the settlement is called mining subsidence [18, 27]. Very great danger and threat to people's lives and their property can be caused by sudden unexpected caving fall of the Earth's surface over the abandoned mining works [3, 7].

According to the report of the Illinois Department of natural Resources [26] and also according to many theoretical and practical knowledge and scientific studies [11, 18, 27] currently, it is not possible to predict precisely how long the mining subsidence events will be finished. From the present experience about 60 to 90 % of the total ground movement occurs within the first few weeks or months of an event. The remaining ground movement continues to develop at a continually decreasing rate and may take 3 to 5 years, or longer. In order to protect the environment, in particular the protection of human life and property, it is necessary to examine mining subsidence on the surface [1, 27]. The most mining subsidence worldwide with their prediction by means of their modelling are examined through the coal fields [8, 10, 16, 28].

Character and size of the subsidence on the surface depends mainly on the geotectonic ratios of rock massif above the mined out area. Knowing the extent of the subsidence trough in mining areas is determining to prevent the entry of persons into these danger zones. Conditioning factors to establish the extent of the movement of the earth's surface above the mined out area are a geodetic way surveyed deformation vectors which can be derived from the processing of measurements at monitoring stations based on these mining tangent territories. 3D (three-dimensional) deformation vectors most adequately characterize movements of ground, buildings and other engineering structures above the mined out area. Deformation modelling is mostly based on periodic monitoring space changes of various engineering structures, buildings or terrain surfaces by means of using the surveying classic terrestrial methods, i.e. measuring 3D observation data elements by using classic optic theodolites and levelling instruments in the 40's up-to 80's of the last century or universal electronic measuring instruments -total stations since the 80's of the last century, or by up-to-date progressive surveying satellite navigation technologies and systems, i.e. Global Positioning System (GPS) and Global Navigation Satellite Systems (GNSS) or very seldom and specific surveying technologies such as the surveying technology - Interferometric synthetic aperture radar (InSAR) or using other advanced specific terrestrial and aerial and space technologies and techniques [4, 5, 15, 16, 23-25, 29, 31]. The deformation vectors are the result of such deformation investigations. The deformation vector with its value gives a global review about the deformation character of the monitored object of interest (earth surface, buildings, engineering structures, etc.) and it also can be used for modelling a future deformation development of such monitored object [5, 11, 18, 27]. Certain specific methods (especially geophysical) for monitoring ground motion must be carried out under controlled large-scale underground works, such as destress blasting or large-chamber mining in ore and industrial mineral deposits [19, 30].

Repeating geodetic measurements in some monitoring stations under deformation investigation of engineering structures, buildings or terrain surfaces can be often complicated in the individual time (periodic) epochs. Monitoring station is presented by a geodetic network with the given structure of the geodetic points on which various geodetic/surveying measurements are realized to determine earth movements or movements of other objects of interest [10]. During the implementation of long-term periodic deformation measurements can occur in various unpredictable obstacles, for e.g. loss or damage or building-up some established geodetic network points due to construction of new engineering structures and buildings or other construction earth works on the monitoring station area. It means that the geodetic network with points at a monitoring station has the non-homogenous structure during all periodical geodetic measurements (during deformation survey).

All these or other unpredictable obstacles make it impossible for periodic execution of the original measurement sights realized at the geodetic network of the monitoring station in time of the first (primary, zero) measuring epoch. It means that for any periodic measurements cannot be maintained equal conditions for realizing measurement sights. The data homogeneity of whole geodetic network in the monitoring station was disrupted. In these cases neither a renewal of the destroyed points (reference and object points) at other places and neither substitution of some values in the geodetic network of the monitoring station (which are not measurable in the successive monitoring epochs) by other variables do not make possible to use a standard method in calculation of the deformation vector [11, 22, 29].

The analysis of time factor of the gradual subsidence development continuing with underground exploitation allows production of more exact model situations in each separate subsidence processes and especially, it provides an upper degree in a prevention of deformations in the surface. Possibility in improving polynomial modelling the subsidence is conditioned by the knowledge to detect position of so-called “break points”, i.e. the points in the surface in which the subsidence border with a zone of breaches and bursts start to develop over the mineral deposit exploitation. It means that the break-points determine a place of the subsidence, where it occurs to the expressive fracture of the continuous surface consistence. 3D deformation vectors locate the places of the break points presenting the subsidence edges [1, 4, 11, 23].

2. Theory for deformation vector specific solution

The geodetic network structure of a monitoring station can be expressively changed between monitoring epochs (epochs with periodic measurements of the observed geodetic data in the geodetic network) by the above-mentioned changes in an original geodetic network and interference with the geodetic points of such network. The most common and efficient way of geodetic networks processing in geodesy and engineering surveying is the network structures estimate based on Gauss-Markov model. The statistics formulation of Gauss-Markov model is as follows [6, 13, 14, 28]

$$v = A(\hat{C} - C^0) - (L_{(0)} - L^0) = Ad\hat{C} - dL \tag{1}$$

$$\textstyle\sum_L = \sigma_0^2 Q_L \tag{2}$$

where $\boldsymbol{v}$ is the vector of corrections of the measured (observed) values L, A are the configuration (modelling) matrix of the geodetic network or also called Jacobian matrix, i.e. the matrix of partial derivatives of functions $L^0 = f(C^0)$ by the vector $C^0, \hat{C}$ is the vector of the aligned 3D coordinate values, C^0 is the vector of the approximate 3D coordinate values, $L_{(0)}$ is the vector of the approximate observation magnitude values of the observed elements in of the first measuring epoch $t_{(0)}$, L^0 is the vector of the approximate observation magnitude values of the observed elements, $d\hat{C}$ is the deformation vector, dL is the vector of the measured values supplements, $\sum_L$ is the covariance matrix of the measured values, σ_0^2 is a priori variance, Q_L is the cofactor matrix of the observations.

It will also be appeared in the changed structures, let us say in a size of the matrixes and vectors A, Q_L, C^0 and L^0. These matrixes and vectors enter into the presupposed model of the network adjustment following out from Gauss-Markov model [6, 13, 22, 28].

If between monitoring epochs there are no changes in the geometrical and observational structure of the geodetic network, then the matrixes and vectors A, Q_L, C^0 and L^0 remain identical for each epoch. Only in such case the deformation vector $d\hat{C}$ can be determined by a conventional procedure according to the following model [27, 28]:

i) in the basic (first) monitoring epoch $t_{(0)}$, we have the vector $\hat{C}_{(0)}$ of the adjusted 3D coordinates of the observed points which are obtained according to Gauss-Markov model

$$\hat{C}_{(0)} = C^0 + (A^T Q_L^{-1} A)^{-1} A^T Q_L^{-1} (L_{(0)} - L^0) = C^0 + G(L_{(0)} - L^0) \tag{3}$$

ii) in other following epochs $t_{(i)}$ we also obtain the vector $\hat{C}_{(i)}$ of the adjusted 3D coordinates of the observed points according to the equation

$$\hat{C}_{(i)} = C^0 + (A^T Q_L^{-1} A)^{-1} A^T Q_L^{-1} (L_{(i)} - L^0) = C^0 + G(L_{(i)} - L^0) \tag{4}$$

iii) thus, for the deformation vector $d\hat{C}$ will be valid the following equation

$$d\hat{C} = \hat{C}_{(i)} - \hat{C}_{(0)} = G(L_{(i)} - L^0) \tag{5}$$

where $L_{(0)}$ and $L_{(i)}$ are the vectors of the observed magnitude values in the epochs $t_{(0)}$ and $t_{(i)}$.

Now we presuppose a case in which some changes in the established geodetic network structure of the monitoring station are occurred during the monitoring observation epochs, i.e. the geodetic network structure between the basic epoch $t_{(0)}$ and the epoch $t_{(i)}$ is changed. Then the origin matrixes and vectors A, Q_L, C^0 and L^0 will be transformed into the following equations

$$\overline{A} = A + dA; \; \overline{Q}_L + dQ_L; \; \overline{C}^0 = C^0 + dC^0; \; \overline{L}^0 = L^0 + dL; \tag{6}$$

According to Equations (6) the vectors $\hat{\overline{C}}_{(0)}$ and $\hat{\overline{C}}_{(i)}$ of the adjusted 3D coordinates of the observed points in the epochs $t_{(0)}$ and $t_{(i)}$ will be determined

$$\hat{\overline{C}}_{(0)} = \overline{C}^0 + (\overline{A}^T \overline{Q}_L^{-1} \overline{A})^{-1} \overline{A}^T \overline{Q}_L^{-1} (L_{(0)} - \overline{L}^0) = \overline{C}^0 + \overline{G}(L_{(0)} - \overline{L}^0) \tag{7}$$

$$\hat{\overline{C}}_{(i)} = \overline{C}^{0} + (\overline{A}^{T}\overline{Q}_{L}^{-1}\overline{A})^{-1}\overline{A}^{T}\overline{Q}_{L}^{-1}(L_{(i)} - \overline{L}^{0}) = \overline{C}^{0} + \overline{G}(L_{(i)} - \overline{L}^{0}) \tag{8}$$

and then the deformation vector $d\hat{C}$ is expressed according to Equation (5) in the form

$$d\hat{\overline{C}} = \hat{\overline{C}}_{(i)} - \hat{\overline{C}}_{(0)} \tag{9}$$

which will not express only 3D changes of the geodetic network points between the particular epochs but the deformation vector can be distorted (biased) by an influence of the geodetic network structural changes. Then deformation vector $d\hat{\overline{C}}$ will not afford the reliable testing information about the concrete deformation consequences.

The presented theory in the cases of some structural changes in the geodetic network can be likely to demonstrate by analytically way if we compare the deformation vector structures $d\hat{C}$ and C expressed according to Equations (5) and (9). Then the structure of the deformation vector $d\hat{\overline{C}}$ is expressed according to Equation (9) and the further equation will be valid

$$\begin{aligned} d\hat{\overline{C}} &= \left[\overline{C}^{o} + \overline{G}\left(L_{(i)} - \overline{L}^{o}\right)\right] - \left[C^{o} + G\left(L_{(0)} - L^{o}\right)\right] = \\ &= \overline{G}\left(L_{(i)} - L^{o}\right) - G\left(L_{(0)} - L^{o}\right) + \overline{C}^{o} - C^{o} \end{aligned} \tag{10}$$

and on the base of Equations (6) and also on the base of the linearization of $\overline{G}$ into $\overline{G} = G + dG$ the following derivation will be valid for the deformation vector $d\hat{\overline{C}}$

$$\begin{aligned} d\hat{\overline{C}} &= (G + dG)\left(L_{(i)} - \overline{L}^{o}\right) - G\left(L_{(0)} - L^{o}\right) + dC^{o} = \\ &= \overline{G}\left[L_{(i)} - \left(L^{o} + dL^{o}\right)\right] + dG\left(L_{(i)} - \overline{L}^{o}\right) - G\left(L_{(0)} - L^{o}\right) + dC^{o} = \\ &= G\left(L_{(i)} - L^{o}\right) + GdL^{o} + dG\left(L_{(i)} - \overline{L}^{o}\right) - G\left(L_{(0)} - L^{o}\right) + dC^{o} = \\ &= G\left(L_{(i)} - L_{(0)}\right) + GdL^{o} + dG\left(L_{(i)} - \overline{L}^{o}\right) + dC^{o} \end{aligned} \tag{11}$$

and finally the deformation vector $d\hat{\overline{C}}$ will be calculated according to the following equation

$$d\hat{\overline{C}} = d\hat{C} + \delta d\hat{C} \tag{12}$$

Equation (15) declares that the deformation vector $d\hat{\overline{C}}$ (calculated with the changed geodetic network structure) is different from its vector of the correct values $d\hat{C}$ only by the term $\delta d\hat{C}$ (i.e. the correction component of the deformation vector corrections). In this case the term $\delta d\hat{C}$ is not generated by spatial movements of the geodetic network points between the individual epochs of measurements, but it is currently generated by changes in the geometric and observational network structure between the particular epochs due to implementation of changes in its point field and also due to changes in measurements in the epochs.

To prevent this problem (so that any depreciation of the deformation vector $d\hat{C}$ is not occurred), which is frequently occurred at the deformation investigation, the following procedures are to using:

- The geodetic network must be carefully projected from the point of view of a maximum and permanent providing its reference points and the line sights between the reference and object points during whole monitoring period, especially.
- If some reference points were lost or destroyed, new points should be established in enough proximity of these lost or destroyed reference points as possible. Same principle is held for the object points.
- If matrixes A and Q_L are expressively changed between the monitoring epochs $t_{(0)}$ and $t_{(i)}$ (for example, in $t_{(0)}$ the geodetic network was measured by a trilateration measurement way, and in $t_{(i)}$ by traverse measurement way, it is necessary to observe more new magnitudes, etc.), then the deformation vector $d\hat{C}$ is determined according the following equations

  $$\begin{aligned} d\hat{C} &= C^0 + (A^T Q_L^{-1} A)^{-1}_{(i)} A^T_{(i)} Q^{-1}_{L(i)} (L_{(i)} - L^0) - \\ &- \left[C^0 = (A^T Q_L^{-1} A)^{-1}_{(0)} A^T_{(0)} Q^{-1}_{L(0)} (L_{(0)} - L^0) \right] \end{aligned} \qquad (13)$$

  and

  $$d\hat{C} = G_{(i)} L_{(i)} - G_{(0)} L_{(0)} - L^0 (G_{(i)} - G_{(0)}) \qquad (14)$$

  because using the identical C^0 and L^0 is not problem to adhere in the individual epochs. Or the deformation vector corrections $\delta d\hat{C}$ are calculated according to Equations (7), (8) and (10), so that the deformation vector $d\hat{C}$ is then corrected according to the introduced Equation (12).

3. Study case example

The monitoring deformation station Košice-Bankov covers an area around the mine field of the magnesite mine in Košice-Bankov. Košice-Bankov is in the northern part of the city of Košice where a popular city recreational and tourist centre of the city of Košice is situated. This popular urban recreational area is located in close proximity to the mine field of the magnesite mine Košice-Bankov (Fig. 1).

Problems of mine damages on the surface, dependent on the underground mine activities at the magnesite deposit, did not receive a systematic research attention in Slovakia till 1976. After that, the requirements for a scientific motivation in the subsidence development following out from rising exploitations and from introducing progressive mine technologies were taken in consideration. The gradual subsidence development at the Košice-Bankov mine region in the east region of Slovakia is monitored by geodetic measurements from the beginning (in the end of sixties of the 20th century) of the mine underground activities in the magnesite mineral deposit.

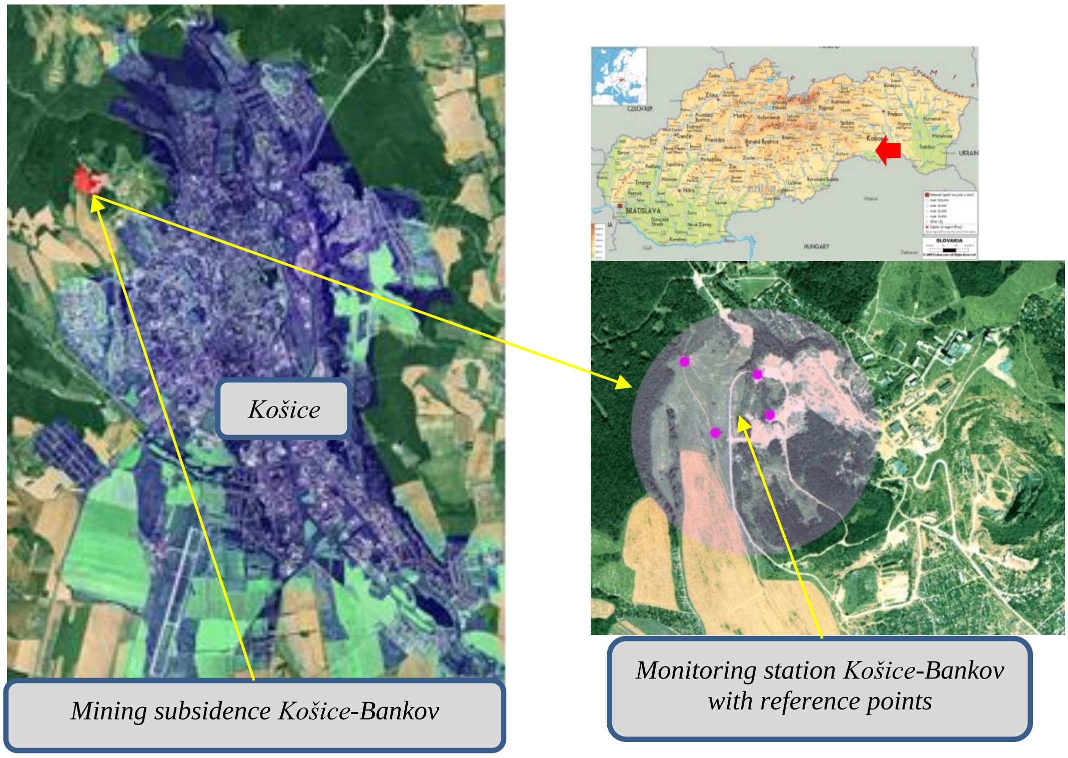

Fig. 1. Ortho-photo map of the city of Košice with a detail view of the mine field Košice- Bankov

Fig. 2. Mining subsidence Košice-Bankov; panoramic view: autumn 2001

Fig. 3. Mining subsidence Košice-Bankov; panoramic view: spring 2002

Fig. 2 and Fig. 3 present the panoramic views to the subsidence Košice-Bankov from the south-west edge of this subsidence in 2001 and 2002 when the magnesite mine was abandoned for two up-to three years.

The monitoring station project in the Košice-Bankov case was designed and realised by the research staff of the Technical University of Košice in Slovakia in 1976. The first observed data were taken from this monitoring station in the same year and each year the spring and autumn geodetic terrestrial and GPS measurements were realized. The monitoring station is situated in the earth surface in the Košice-Bankov mine region near by the shaft under the name - West shaft. The monitoring station is constructed from the geodetic network of the reference points (No.: 01A, 01B, 01C, 01D) and objective points (78 points) situated in geodetic network profiles (Fig. 4). Some of the reference points were destroyed by the subsidence processes.

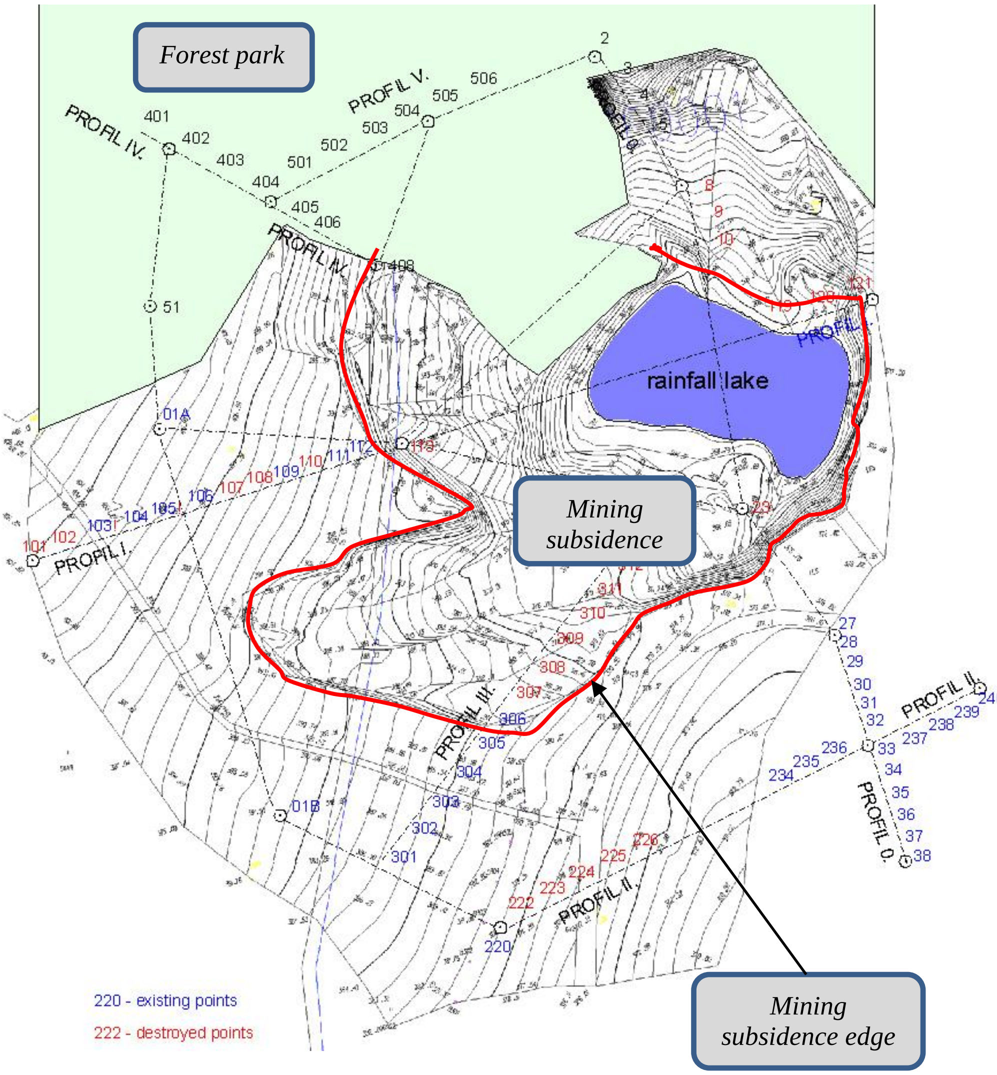

Fig. 4. Monitoring station Košice-Bankov (1:2,000); (Reference points 01C and 01D → destroyed points)

All surveying profiles of the monitoring station Košice-Bankov are deployed across and along the expected movements in the subsidence (Fig. 4). 3D data were firstly observed by 3D (positional and levelling measurements) terrestrial geodetic technology (since 1976) using classic optical geodetic theodolites and levelling devices for very high precision levelling, later total electronic surveying devices and also devices for GPS/GNSS technology (since 1997), i.e. Trimble 3303DR Total station, GPS: ProMark2 and GNSS: Leica Viva GS08. Periodic monitoring measurements are performed at the monitoring station Košice-Bankov twice a year (usually in spring and autumn) [28]. In 1981, some points of this monitoring station were destroyed (defective) and again replaced in same year (points No.: 2, 3, 30, 38, 104, 105 and 227[*] on the profiles No.: 0, I and II). To defect of these points to occurred by some fit for felling works in close forest crop. The destroyed points were replaced very precision geodetic way according the origin coordinates.

4. Accuracy and quality assessment of the network

1D, 2D and 3D accuracy of the geodetic network points (the monitoring station Košice-Bankov) in the East Slovak region was appreciated by the global and the local indices. The global indices were used for the accuracy consideration of whole network, and they were numerically expressed. We used the variance global indices: $tr(\sum_{\hat{C}})$, i.e. a track of the covariance matrix $\sum_{\hat{C}}$ and the volume global indices and $\det(\sum_{\hat{C}})$ i.e. a determinant. The local indices were as a matter of fact the point indices, which characterize a reliability of the network points:

- mean 3D error $\sigma_p = \sqrt{\sigma^2_{\hat{X}_i} + \sigma^2_{\hat{Y}_i} + \sigma^2_{\hat{Z}_i}}$, ,
- mean coordinate error $\sigma_{XYZ} = \sqrt{\dfrac{\sigma^2_{\hat{X}_i} + \sigma^2_{\hat{Y}_i} + \sigma^2_{\hat{Z}_i}}{3}}$,
- confidence absolute ellipses or ellipsoids, which were used for a consideration of the real 2D or 3D in the point accuracy. We need to know the ellipsis constructional elements, i.e.: semi-major axis a, semi-minor axis b, bearing φ_α of the semi-major axis and ellipsoid flattening f, ($f = 1 - b/a$).

Characteristics of the network quality are mainly accuracy and reliability. Position accuracy of points can be expressed in addition to numerical also by graphical indicators of the network accuracy, which are the confidence curves and a confidence ellipse (confidence ellipsoids in 3D case). Ellipsoids determine a random space, in which the actual location of points will be lie with a probability *1-α*, where *α* is chosen level of significance, according to which the ellipsoids are of different size. In geodetic practice the standard confidence ellipsoids are used for 3D space. Their design parameters can be derived either from of the cofactor

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[*] The reference point No. 227 (profile II) was rebuilt instead of the point No. 226.

matrix Q_L of the adjusted coordinates, which shall be these design parameters on the main diagonal, or from the coordinate covariance matrix of the coordinate estimations $\sum_{\hat{C}}$ of the determined points, which shall be them on the main diagonal.

All calculated data according to the presented specific theory about the deformation vector estimation in a case of any accepted changes in the geodetic network of the monitoring station are in Tabs. 1-5. In general way Tabs. 1-5 are focussed on the accuracy and quality assessment of the geodetic network (Tab. 1: mean errors, Tab. 2: absolute confidence ellipse elements, Tab. 3: global indices, Tab. 4: local indices, Tab. 5: values of deformation vector). Tabs. 1-5 comprehend the adjusted mean errors of the individual coordinates, global and local 3D indices and their absolute confidence ellipsoid elements determining 3D accuracy of some chosen replaced points. The numbers in front of the back slash belong to year 1976 when geodetic measurements were started. The numbers after the back slash belong to 2014[†] when all geodetic measurements were finished. In 2007 the points No.: 2, 3, 30, 38, 104, 105 and 227 were re-stabilized due to small earth construction works needed to the preparation works for a future reclamation of the mining territory Košice-Bankov.

Tab.1. Mean errors (year 1976 / year 2014)

Point	m_X [mm]	m_Y [mm]	m_Z [mm]
2	15.7 / 16.4	32.9 / 45.5	12.5 / 72.4
3	14.8 / 34.3	27.2 / 58.9	30.5 / 69.1
30	21.1 / 25.6	26.5 / 24.1	45.5 / 32.7
38	16.6 / 14.9	16.3 / 8.1	20.1 / 18.4
104	18.2 / 41.3	34.1 / 69.0	55.4 / 78.0
105	28.2 / 31.6	17.1 / 21.1	9.9 / 17.8
227	20.0 / 16.9	8.5 / 4.7	10.9 / 10.8

Tab. 2. Absolute confidence ellipse elements (year 1976 / year 2014; $\alpha = 0.05$)

Point	a_i [mm]	b_i [mm]	φ_{a_i} [gon]	f
2	49.9 / 51.0	5.9 / 5.1	172.303 / 172.695	1.8818 / 0.9
3	40.8 / 32.5	12.3 / 3.7	172.704 / 179.151	0.6985 / 0.8862
30	43.0 / 45.9	18.2 / 21.5	160.340 / 160.058	0.5767 / 0.5316
38	23.5 / 28.1	21.8 / 22.4	40.966 / 41.203	0.0723 / 0.2028
104	47.5 / 79.2	24.0 / 9.9	211.146 / 217.148	0.4947 / 0.875
105	42.8 / 42.4	15.3 / 17.6	370.337 / 370.624	0.6425 / 0.5849
227	28.8 / 25.2	8.1 / 10.9	19.634 / 19.781	0.7188 / 0.5675

[†] Deformation survey on the monitoring station Košice-Bankov without the reclamation works intervention was finished in the autumn 2014.

Tab. 3. Global indices (year 1976 / year 2014)

Rank $rk\ (\Sigma_{\hat{C}})$	**Track** $tr\ (\Sigma_{\hat{C}})$ [mm^2]	**Determinant** $det\ (\Sigma_{\hat{C}})$ $.10^{25}$	**Average mean error** $\sigma_{\hat{C}_{pr}}$ [mm]	**Norm** $nor\ (d_{\hat{C}})$ [mm]
14/14	7041.901 / 7041.054	2.869 / 2.869	22.428 / 22.971	124.218 / 126.155

Tab. 4. Local indices (year 1976 / year 2014)

Point	**Mean 3D error** σ_p [mm]	**Mean coordinate error** σ_{XYZ} [mm]
2	36.4 / 37.5	25.7 / 18.8
3	30.9 / 28.4	21.8 / 24.5
30	33.9 / 33.0	23.9 / 23.0
38	23.3 / 26.7	16.5 / 13.8
104	38.6 / 14.1	27.3 / 54.9
105	32.9 / 27.4	23.3 / 19.9
227	21.7 / 22.5	15.3 / 17.4

Tab. 5. Deformation vector values (year 2014)

$d\hat{C}$	**Point**						
	2	**3**	**30**	**38**	**104**	**105**	**227**
[mm]	2.4	- 2.9	-8.0	6.7	-4.0	0.6	9.7

The deformation vector values confirm possibility in the deformation vectors valuation according to the presented theory [29]. However, the deformation vector values need not mean any displacement of the points. In spite of the fact that the network points were adjusted according to the conventional manner by Gauss-Markov model, the deformation vector values can be burdened by the accumulation of surveying errors. Therefore, for their prominence testing it is required to carry out testing the deformation vector by the global and localization test of the congruence (see chapter 5). In the last surveying during the spring 2014 the deformation vectors on the tested points (No.: 2, 3, 30, 38, 104, 105 and 227) of the monitoring station were ranged from 9.7 mm (point No. 227) to -8.0 mm (point No. 30) (Tab. 5, Fig. 5). 3D mean errors were ranged from 14.1 to 37.5 mm (year 2014), and the mean coordinate errors were from 13.8 to 54.9 mm (year 2014) (Tab. 4). In autumn 2014 all points of the monitoring station Košice-Bankov were destroyed by the reclamation works, i.e. the reference points were removed and the object points were backfilled by the secondary imported soil from various land building and excavation works in and around of the city of Košice.

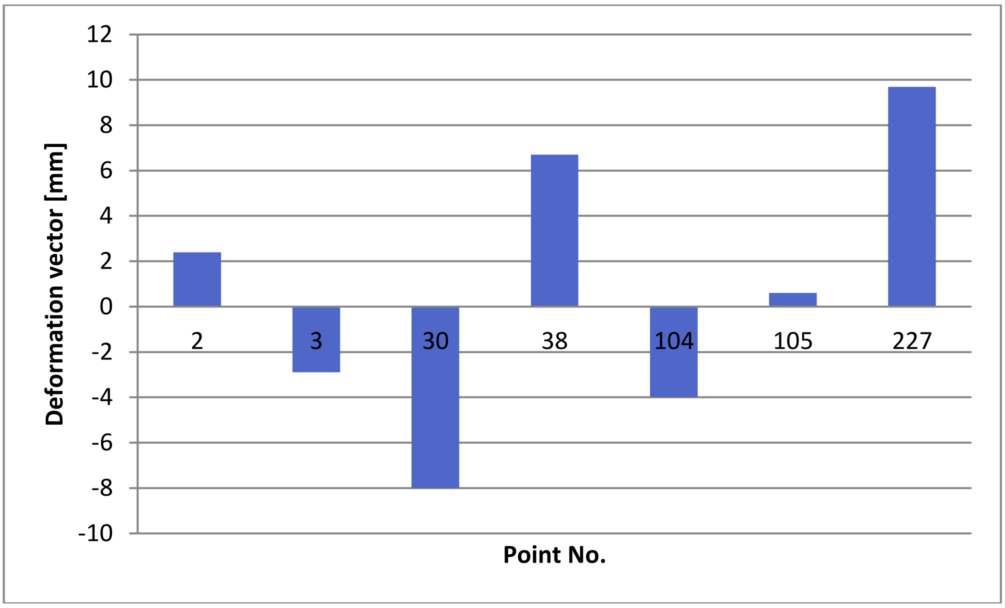


Fig. 5. Graphical representation of the deformation vectors on the tested monitoring station points; year 2014

5. Global test of the congruence

Significant stability, respectively instability of the network points is rejected or not rejected by verifying the null-hypothesis H_0 respectively, also other alternative hypothesis [21, 28].

$$H_0 : d\hat{\overline{C}} = 0; \qquad H_\alpha : d\hat{\overline{C}} \neq 0 \tag{15}$$

H_0 expresses an insignificance of the coordinate differences (deformation vector) between epochs $t_{(0)}$ and $t_{(i)}$.

To testing can be use e.g. test statistics T_G for the global test

$$T_G = \frac{d\hat{\overline{C}} Q^{-1}_{d\hat{\overline{C}}} d\hat{\overline{C}}^T}{k\bar{s}_0^2} \approx F(f_1, f_2) \tag{16}$$

where $Q_{d\hat{\overline{C}}}$ is the cofactor matrix of the final deformation vector $d\hat{\overline{C}}$, k is the coordinate numbers entering into the network adjustment ($k = 3$ for 3D coordinates) and $\bar{s}_0^2$ is the posteriori variation factor common for both epochs $t_{(0)}$ and $t_{(i)}$.

The critical value T_{KRIT} is searched in the tables of F distribution (Fisher–Snedecor distribution) tables according to the degrees of freedom $f_1 = f_2 = n - k$ or $f_1 = f_2 = n - k + d$, where n is number of the measured values entering into the network adjustment and d is the network defect at the network free adjustment. Through the use of methods MINQUE is $s_0^{2t(0)} = s_0^{2t(i)} = \bar{s}_0^2 = 1$ [21, 28]. The test statistics T should be subjugated to a comparison with the critical test statistics T_{KRIT}. T_{KRIT} is found in the tables of F distribution according the network stages of freedom.

Two occurrences can be appeared:

1. $T_G \leq T_{KRIT}$: The null-hypothesis H_0 is accepted. It means that the coordinate values differences (deformation vectors) are not significant.
2. $T_G > T_{KRIT}$:The null-hypothesis H_0 is refused. It means that the coordinate values differences (deformation vectors) are statistically significant. In this case we can say that the deformation with the confidence level α is occurred. Tab. 6 presents the global testing results of the geodetic network congruence.

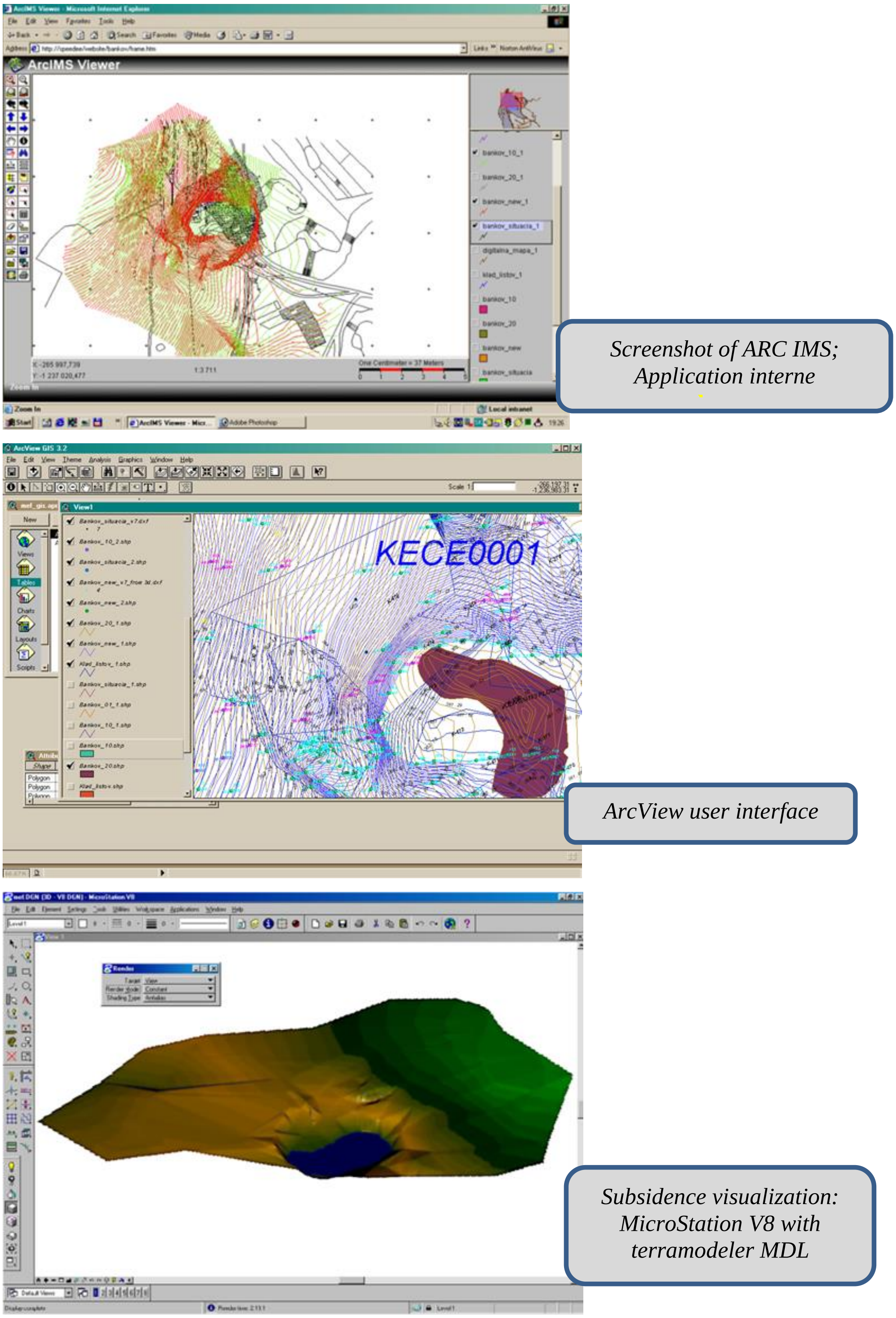
Tab. 6. Test statistics results of the geodetic network points of the monitoring station Košice-Bankov

Point	$T_{G(i)}$	$<\ \leq\ >$	F	**Notice**
2	1.297	<	3,724	deformation vectors are not significant
3	3.724	≤		
30	3.501	<		
38	3.724	≤		
104	2.871	<		
105	1.403	<		
227	2.884	<		

6. Mining subsidence in GIS for mining landscape reclamation

GIS (Geographical Information Systems) of the mining landscape Košice-Bankov is based on the next decision points [29]: basic and easy observed geo-data presentation, basic database administration and wide information availability. The best viable solution is to execute GIS project as the Free Open Source application available on Internet. The general facility feature is free code and data source viability through the HTTP and FTP protocol located on the project web pages. Inter among others features range simple control, data and information accessibility, centralized system configuration, modular stuff and any OS platform (depends on PHP, MySQL and ArcIMS port) [2, 12, 17, 29, 32, 33]. Network based application MySQL is in a present time the most preferred database system on Internet and it was applied also on the deformation survey outputs from the monitoring station Košice-Bankov.

The database part of GIS for the subsidence Košice-Bankov at any applications is running into MySQL database (Fig. 6). 3D model of the mining subsidence Košice-Bankov with GIS multilayers applications were delivered to the reclamation plan of the Municipality of the city of Košice.



Screenshot of ARC IMS; Application interne

ArcView user interface

Subsidence visualization: MicroStation V8 with terramodeler MDL

Fig. 6. ArcView user interface subsidence visualization

Given the fact that extraction of magnesite has been completed at the mine Košice-Bankov and these mine workings are abandoned since the end of the 90-years of the last century and whole mining territory Košice-Bankov with the huge mining subsidence on the conclusions of the deformation investigations are stable, the Municipality of the city of Košice adopted the plan for the reclamation of that mine landscape. Numerical and graphical presentation of long-term investigations on the deformation monitoring station Košice-Bankov with their successive test analyses of the deformation vectors confirmed stability of the mining subsidence and surrounding mining area. The mining subsidence and by mining activities devastated all surroundings around the mine plant of huge proportions (mining pit heaps, excavations and other mining earth-works, etc.) began gradually to backfill by a secondary imported soil. The reclamation works on the basis of the investigation geodetic deformation conclusions around the former mining area Košice-Bankov began at the beginning of this century. Some final reclamation works were completed in summer 2016.

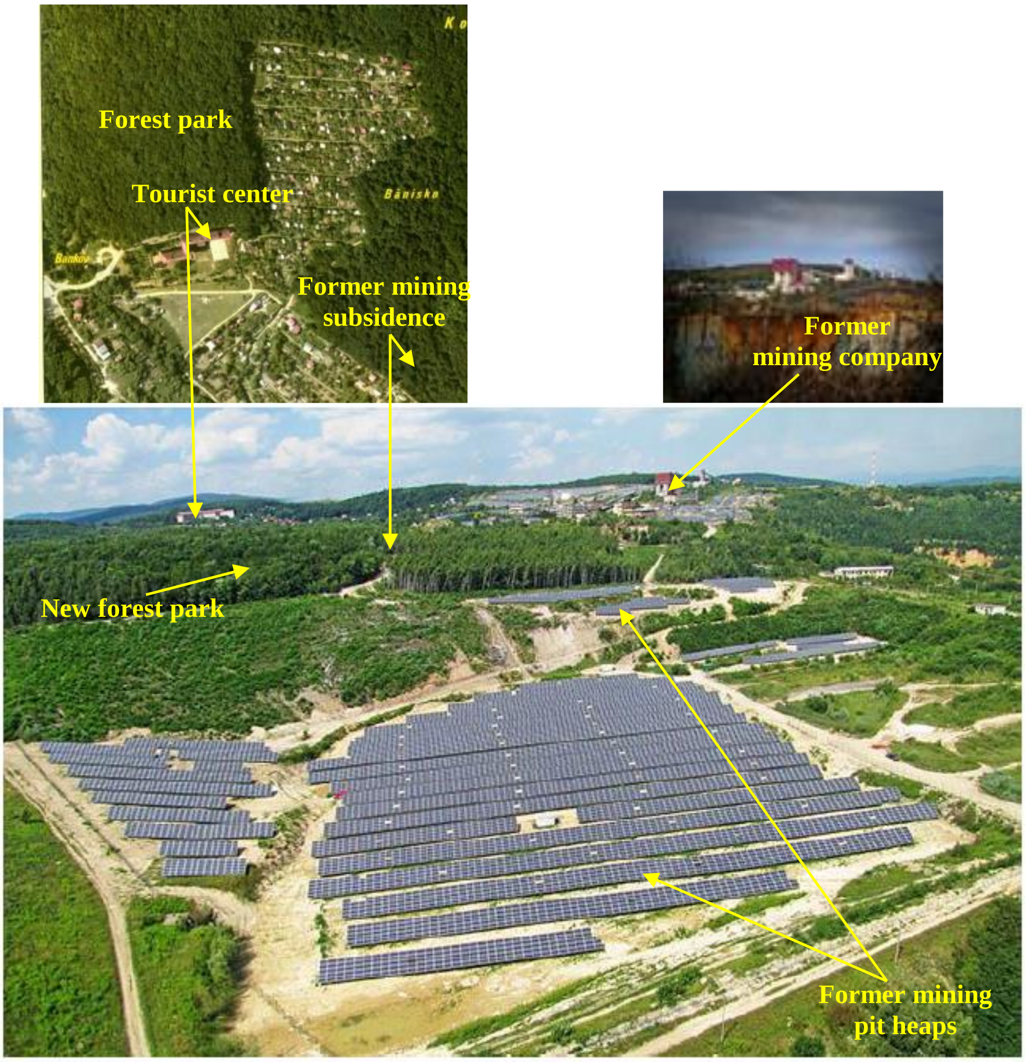


Fig. 7. Mining subsidence and surrounding (Košice-Bankov) after reclamation; panoramic view: summer: 2016. Solar collectors on the site of the former mining pit heaps; afforesting (in the background) on the site of the former mining subsidence

On the territory of the former extensive mine subsidence area the forest park Košice-Bankov was built as the environmental green-forest part of the urban recreation area of the city of Košice. The mining subsidence began gradually to backfill by imported natural material from many construction and earth-works in the city of Košice and surroundings of the city. Such sporadic embankment works took too long, i.e. more than years. After completion of the embankment and other earth-works the forest park Košice-Bankov was built on the territory of the former mining subsidence (Fig. 7). It was planted in particular birch trees. These trees are known by their unpretentiousness onto natural base and also by a rapid growth. Currently, birch grove constitutes by five to six years-old healthy tree.

Finalization of building the recreation area Košice-Bankov was completed in spring 2016. It has also reclaimed the mining pit heaps and the devastated surrounding territory of the former mining plant. On the site of the former mining pit heaps the solar collectors were built which contribute to renewable energy for the city of Košice (Fig. 7).

7. Conclusions

Determination of the deformation vectors as the differences between the adjusted coordinate vectors obtained from two measured monitoring epoch in the geodetic networks is possible if the geometric observation network structure between the individual monitoring epochs is strictly saved. This research article presents the theory and practical outcomes about a possibility of the deformation vector solutions in the geodetic network of the monitoring station in a case of violation of the geodetic network structure during the period of monitoring movements of the earth's surface. The solved deformation vector affords unreliable image about 3D changes of the geodetic network points in a frame of some specific deformation investigation, e.g. ground movements, mining subsidence, land-slides, dams, engineering constructions, buildings, or other building objects.

The largest differences in all tested elements shown in Tabs 1-5, especially the largest deformation vectors in Tab. 5 and Fig. 5 were occurred on displacement of the point No. 30 and No. 227. Due to the fact that the tested deformation vectors on these points were not significant according to the test statistics, we can declare these points as the static ones. The study case example confirmed availability and applicability of the presented theory on the deformation vector in a special occasion of deformation measurements at mining subsidence, where many violations in the geodetic structure of the monitoring station are occurred. Despite the validity of the verified presented method in solving specific deformation vector in the data non-homogeneous geodetic network points at the monitoring station may cause a distortion of the deformation effects in the monitoring territory. Therefore, maintaining data-homogeneity of the geodetic network structure should be a priority for whole periodicity of each deformation surveys.

The modelling mining subsidence in GIS from the Košice-Bankov mining area was delivered to the Municipality of the city of Košice to solution of the landscape planning to the future environmental rehabilitation of this abandoned old mining region such as the magnesite mines Košice-Bankov. Determination of the deformation vectors of the monitoring station in the undermined landscape of the abandoned magnesite mine Košice-Bankov was important in delimitation and specification of the edges of the mining subsidence and the edge-punched zones of the subsidence with a lot of cracks and fissures. Very precise identification of the 3D position of such delimitation of the subsidence was a basic document for the plan preparation of the Municipality of the city of Košice for the reclamation of the former mining area Košice-Bankov as well as and the local ambient by mining activity affected landscape for a comprehensive revitalization and broadening recreational area in the suburban zone of the city of Košice. The Municipality of the city of Košice has 3D model of the mining subsidence Košice-Bankov in GIS with possibilities of modelling natural and industrial disasters, which largely can be the helpful tools for many reclamation works in the landscape ecosystem restoration with the basic elements of safety measures against possible unforeseen and possible consequences of the former mining activities to protect the health and lives of people moving in the forest park in the former magnesite mine Košice-Bankov.

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